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A Strategic Evaluation of Factors Affecting the Adoption of Timber Bridges

The Role of New Technology Adoption in the Timber Bridge Market: Special Project Fiscal Year 1992

PREFACE

This publication is a technology transfer effort by the USDA Forest Service, Timber Bridge Information Resource Center, in cooperation with the Center for Forest Products Marketing, Department of Wood Science and Forest Products, at Virginia Polytechnic Institute and State University, under a grant from the USDA Forest Service.

This publication is designed to be a final report to the sponsors of the research. It summarizes the various stages of the study and conclusions drawn from the investigations. Also, it examines factors that influence the adoption of timber bridges and how they affect the decision process. It discusses current marketing practices of timber bridge promoters and mentions strategies that will assist in increasing the adoption of new bridge technology.

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Other publications in this five-part series are:

Factors Influencing the Adoption of Timber Bridges (Literature Review), NA-TP-02-95 (Part I)
A Perceptional Investigation into the Adoption of Timber Bridges, NA-TP-03-95 (Part II)
A Hierarchial Analysis of Bridge Decision Makers, NA-TP-04-95 (Part III)
Marketing Practices in the Timber Bridge Industry: 1993, NA-TP-05-95 (Part IV)

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Timber Bridge Information Resource Center

TECHNOLOGY
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The Role of New Technology Adoption in the Timber Bridge Market: Special Project Fiscal Year 1992

A Strategic Evaluation of Factors Affecting the Adoption of Timber Bridges

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Timber Bridge Information Resource Center

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EXECUTIVE SUMMARY

A comprehensive study was undertaken to determine the barriers and incentives that continue to exist for timber bridge adoption across the United States. The study began with a comprehensive literature search of secondary information in the areas of timber bridges, innovation, barriers to entry of new products, and decision-making theory. Input was sought from qualified industry and university personnel.

The first stage of primary data collection included a mail survey to more than 1,300 highway officials across the country to measure perceptions of various bridge materials (prestressed concrete, steel, timber, and reinforced concrete). Timber was perceived to be the poorest in overall performance and rated lowest on four of eight pre-selected material attributes (low maintenance, easy to design, long life, and high strength). Physical characteristics of timber rated lower than design characteristics. The Midwest and Northeast regions of the United States rated timber higher in overall performance than other regions.

The six most important criteria in choosing a bridge material were used to model the decision process using the Analytic Hierarchy Process. The top criteria, as rated by the mail survey, included:

- *expected lifespan of material*
- *past performance*
- *maintenance requirements*
- *resistance to natural deterioration*
- *initial cost*
- *lifecycle cost of material*

Engineers and highway officials in four states (Mississippi, Virginia, Washington, and Wisconsin) were personally interviewed to gather data for the AHP model. Officials were classified as either state Department of Transportation employees, private consultants, or local highway officials. The rating of the six criteria were similar by state; however, their effect on the material choice (prestressed concrete, steel, timber, and reinforced concrete) varied by region. Prestressed and reinforced concrete were the material of choice by each decision group within each state.

The final phase of the investigation included a mail survey to existing manufacturers of timber bridge materials to understand their marketing and manufacturing practices. Sales of responding firms ranged between 1.3 million to more than 2 billion dollars; however, sales from timber bridge materials represented 7% of total sales. Wood treating and glue-laminating firms represented 75% of responding firms.

The information gathered by these three studies led to the development of strategies for the timber bridge industry. The factors that have the greatest influence on adoption appear to be a strong marketing effort by manufacturers, timber designs in state bridge standards, resistance to deicing chemicals, and strong control of rural bridges by local officials. Factors that appear to impede adoption include strong state control of local roads, no timber bridge design standards, perceived high wood decay rates, low cost of concrete bridges, and lack of an active marketing effort.

The size of the timber bridge market was estimated based on answers to open-ended questions by highway officials in the mail survey, personal interviews, and bridge data obtained from the Federal Highway Administration. It is unlikely to exceed 600 to 700 bridges a year or 10 to 12 million board feet of lumber.

INTRODUCTION

Background

Recently, the modern timber bridge has entered the bridge replacement market in the United States (USDA 1990). Wood is probably the oldest bridge-building material, and new technological innovations allow under-utilized species to be built into rural highway bridges. With an estimated 84 billion dollar backlog for bridge replacement and rehabilitation in the United States (USDOT 1991), a market opportunity exists for the forest products industry to expand into this area.

During the winter of 1992, a study was undertaken at Virginia Tech in cooperation with the USDA Forest Service to investigate the factors that affect the adoption of timber bridges. With a thorough understanding of these factors, their influence on the bridge decision process, and an understanding of current marketing practices of timber bridge promoters, strategies can be developed that will assist in increasing adoption of new bridge technology. By directing efforts to areas in which this technology will have the greatest potential, rural economic development can be enhanced.

One of the most difficult strategic decisions for management to evaluate is the expansion into new product areas. This may be attributed to a failure rate that ranges between 35% (Crawford 1979) and 80% (Swasy 1990). Yet, it is known that new products are vital for long-term economic growth of a company. From the period between 1978 to 1986, the contribution of new products to profits in all U.S. industries rose from 23% to 32% of total profits (Sarin and Kapur 1990). New products become increasingly important as the industry approaches maturity. This trend has been witnessed recently in the forest products industry as firms move from standard commodity items to differentiated and specialty products (Rich 1986, Sinclair 1992).

New product success has been attributed to a strong marketing orientation (e.g., Cooper 1990, Cooper and Kleinschmidt 1987, Hopkins and Bailey 1971, Swasy 1990). Marketing research is the first step in identifying and meeting customer needs. However, all too often, market research is done after the development of the product to verify market acceptance.

Successful products have market input into the design decisions to meet customer expectations (Cooper 1990). This market orientation has been directly attributed to business profitability (Narver and Slater 1990). Therefore, this concept is increasingly important to the forest products industry as timber resources change, or become limited, and international competition increases.

C.W. Bingham, Vice-President of Weyerhaeuser Inc., stated that forest products firms must develop innovative specialty products and seek out discrete market segments to be successful (Bingham 1986). This research will provide information necessary for firms interested in expanding into the bridge market.

The first part of this study has determined, through a mail survey to over 1,300 bridge decision makers in the United States, that timber is perceived to be the poorest performing bridge material. Prestressed concrete was rated the highest, followed by reinforced concrete, steel, and timber. The most important non-structural factors in the bridge decision (of the twenty-three measured) include:

- *lifespan*
- *past performance*
- *maintenance*
- *resistance to natural deterioration*
- *initial cost*
- *lifecycle cost*

These factors were similar across three decision groups (state DOT engineers, private consultants, and local highway officials) and five distinct geographic regions (Northwest, South, Mid-Atlantic, Northeast, and Midwest). Timber was rated the lowest on the material attributes of:

- *maintenance*
- *ease of design*
- *long life*
- *high strength*

The most common concerns with timber were decay in the substructure of the bridge and continued maintenance.

These are areas that manufacturers need to address in order to increase acceptance of timber bridges. Only on the attribute of ease of construction did timber rate above reinforced concrete, and timber never rated above prestressed concrete. Decision makers preferred prestressed concrete because of its pre-fabrication, tight quality control measures, standard sizes, long life, and ease of construction.

Timber was rated higher in performance by decision makers in the Northeast and Midwest United States. The Mid-Atlantic and the South rated timber the poorest performing material. Local highway officials perceived timber to be better than did state DOT and private engineers. Those who have tried timber within the past five years, or have participated in the recent Timber Bridge Initiative, perceived timber to be better than those who have not.

In the second segment of the research, the decision model Analytic Hierarchy Process (AHP) was applied to the six major factors (criteria) in the bridge decision process to determine their importance in the choice of a bridge material in four selected states. Personal interviews were conducted with more than seventy engineers in the states of Mississippi, Virginia, Washington, and Wisconsin. In every state, either prestressed or reinforced concrete was the material decision based upon these criteria. The most important criteria were maintenance requirements, initial cost, and past performance of material. Only in Wisconsin was timber the second choice by county engineers. Every state DOT and private consulting engineer favored either prestressed concrete or reinforced concrete.

The results of this part of the study indicate that timber will seldom be chosen as the rural bridge material based upon these six criteria. The only criteria that affected the choice of timber was *initial cost*. As cost becomes more important in the decision, timber may be considered. This part of the study also concluded that rural decision makers are more likely to choose timber than are state or consulting engineers. This is where marketing efforts may be most successful.

In the final segment of the research, more than sixty manufacturing firms currently involved in the promotion of timber bridges were surveyed to understand marketing and manufacturing practices. Wood treating and glue-laminating plants represented over 75% of responding companies. Manufacturing facilities were located predominantly in the Western U.S., and marketing efforts were highest in the Midwest. Timber bridge sales account for approximately 7% of total sales of the responding firms. Southern pine and Douglas fir were the main species currently utilized in bridge construction. Only 40% (12) of the firms responding supplied a complete timber bridge package, and seven of these provided engineering plans with the bridge.

One-third of the responding companies used an outside sales staff for marketing their bridges. Other elements of the promotional mix included sales literature, displays at trade shows, providing engineering assistance, advertising, and seminars. Timber bridge promoters felt that individual preferences and specifications are more important in the decision than did bridge engineers.

Timber Bridge Adoption

The modern timber bridge can be considered a major innovation that highway officials are being asked to adopt as part of their bridge replacement programs. Adoption decisions must consider the response of the customer to technological alternatives. Resistance to these changes by end users can be expected and is a valuable source of information (Ellen et al. 1991). These authors state that part of the problem is that potential adopters may not perceive the benefits or risks in the same way as the planners of the innovation. Resistance to innovation has been called the *less developed concept* in diffusion research (Sheth 1981).

There are numerous examples of difficulty in introducing new products into the industrial marketplace. Adoption of new products has been slower than expected, provided lower profit margins, required greater resources than originally planned, and in many cases, resulted in withdrawal from the market. Many barriers exist that may be unseen, unanticipated, and unmanaged, resulting in rejection of the innovation by potential buyers of a superior product (More 1986). Entry barriers have been defined by Porter (1980) as features of an industry that give incumbents an inherent advantage over potential entrants. Little is known of the barriers that inhibit adoption, the incentives that may contribute to the use of wood, the realistic potential market share for wood in this market, and the marketing strategies necessary to increase the adoption rate.

Five major factors (Table 1), which may act as barriers or incentives to timber bridge adoption, have been identified in this study:

- *conditions*
- *decision makers*
- *demand*
- *familiarity*
- *resources*

For the timber bridge industry to continue to expand, it is necessary to have a thorough understanding of these factors and how they affect the material choice decision by bridge officials. Although more than 272 modern timber bridges have been funded since 1989 (USDA 1993), much of this success can be attributed to current monetary incentives for their adoption. This study has determined that negative perceptions of timber as a bridge material continue to exist, and manufacturers will need to address these perceptions if the use of wood for rural bridges is to increase.

Objectives

It is the objective of this final chapter to identify the barriers and incentives that continue to exist for timber bridge adoption. These factors were analyzed in depth as case studies in four selected states. The realistic market size will be determined from current Federal Highway Administration data (FHWA 1993), and the market segments with the greatest potential to use this technology will be identified. Marketing strategies will be suggested which will enable promoters of timber bridges to direct their efforts in the most efficient manner. Areas of future study will be identified which will enable scientists to continue this important work.

METHODS

The results reported in the following sections are based on a mail survey to over 1,300 highway officials in twenty-eight states, personal interviews with more than 70 engineers in four states, and a mail survey to over 60 current timber bridge manufacturers. Open-ended questions via the mail surveys and discussions with highway officials led to the identification of barriers and incentives that exist for timber bridge adoption.

RESULTS AND DISCUSSION

Incentives and Barriers to Timber Bridge Adoption

Much has been reported on the advantages of timber in bridge construction (Gutkowski and Williamson 1983, Muchmore 1986, Ritter 1990). These positive characteristics can be considered incentives to increase adoption rates of timber bridges. In this study, engineers and highway officials identified reasons for using timber in bridges. The most important incentives include:

- *ease and speed of installation*
- *ease of repair*
- *timber is not affected by deicing chemicals*
- *aesthetics*

Although in open-ended questions, timber was repeatedly suggested because of aesthetics, this study discovered that decision makers rated prestressed and reinforced concrete higher on this attribute. Aesthetics rated quite low on the list of factors important in the bridge material choice decision. This may indicate that although many highway officials feel timber is aesthetically pleasing, this is not an important factor in choosing a bridge material.

Other incentives are summarized in Table 2. These represent potential competitive marketing advantages that timber may possess over the other bridge materials.

Ou and Weller (1985) identified the disadvantages of timber in bridges as:

- *decay*
- *fire*
- *deep members*
- *long fabrication times*
- *moisture retention*

This study lists important barriers to the adoption of timber bridges (Table 3) as:

- *short lifespan*
- *high maintenance*
- *excessive deflection*
- *high cost*
- *environmental concerns*
- *poor performance under heavy and/or high volume traffic*

Although problems with timber bridges were recognized in the mid-eighties, many of the same barriers exist today. Manufacturers and timber design engineers must address the barriers that continue to retard adoption of modern timber bridges.

Case Studies

The following section discusses in depth the results from interviews with decision makers in four states regarding timber bridges. Much of the information is qualitative in nature in order to establish the bridge replacement situation in each state. Table 4 is a summary of these results for ease of interpretation.

Mississippi — With an estimated 8,000 deficient bridges, this state would appear to be well placed for increased adoption of timber bridges. Nearly 20% of current structures are made of timber, and current replacement with timber bridges is 17% (FHWA 1993). Yet, perceptions of timber in Mississippi was one of the poorest of the states studied. In discussions with DOT and county engineers (who are private consultants appointed for 4-year terms), it was found that most of the timber bridges are built to no design standards. Local elected officials or county road personnel often replace closed or restricted bridges (structures that should not be carrying the weight of regular traffic) with either creosote-treated timber, used steel trusses, old railroad flat cars, or used precast concrete decks. This choice depends heavily upon what material is available and least expensive. The role of the county engineer may be only to determine the size of the structure.

All state and federally funded bridges may be designed by the county engineer. Mississippi relies heavily on standard bridge plans, of which timber is not included. Although the county engineer makes the replacement decision, all those interviewed stated they followed standard state bridge plans. The material of choice was prestressed concrete, resulting from its ease of construction, long lifespan, and low cost.

This state had the lowest average total bridge costs of states interviewed with a range of $30 to $35 per square foot for prestressed concrete. This compares to current Timber Bridge Initiative costs that range between $35 to $120 per square foot of superstructure (USDA 1993). Mississippi replaces, on the average, nearly 175 bridges a year (FHWA 1992).

Timber bridges in the state have not performed well. The fact that these bridges may not have been well designed was not important to highway officials. Engineers stated that the average lifespan was only 25-30 years. Decay in piling and substructure material was quite common. High maintenance is the other consideration engineers disliked about timber. Timber bridges are being replaced regularly with prestressed concrete. This process will most likely continue until it can be proven that timber bridges can last 50 years, and that timber is cost competitive.

There are 10 treating plants in Mississippi that can supply the timbers that go into replacement bridges. The sawtimber resource is approximately 73 billion board feet, one-half of which is softwoods (USDA 1989). Loblolly and shortleaf pine make up the majority of softwoods, and most of the hardwood resource is red oak, white oak, and sweetgum. There is no continued active marketing of timber bridges in the state. The Timber Bridge Initiative has sponsored 8 bridges since 1989, and the State Forestry Commission has supported their efforts. Highway engineers feel these structures have been expensive and provide no real advantage over prestressed concrete.

Marketing efforts in Mississippi need to address getting timber bridges included in the standard bridge plans. Working with the secondary roads program of the State DOT would be the place to start. Initial cost, resistance to natural deterioration, and maintenance requirements were the most important factors in the bridge decision in this state. Since substructure decay is the primary concern with timber, efforts should focus on promoting a complete timber superstructure on concrete abutments. Advantages of timber include speed of installation, ability to use local work crews, reduced maintenance of modern designs, and the ability to rehabilitate existing bridges. Costs of timber bridges will have to be competitive with prestressed concrete for wide acceptance.

Virginia — Of the states interviewed, Virginia's Department of Transportation (DOT) has the largest control of rural roads (97%). Virginia is divided into nine highway districts with a chief bridge engineer directing maintenance and replacement for rural bridges in each district. Most rural bridges are designed at these locations. The central office in Richmond is responsible for State and Federal highway bridge replacement. Private consultants are used occasionally as workload dictates. Virginia has the smallest number of timber bridges of the states interviewed (60, and 3 TBI sponsored bridges). Virginia has approximately 4,000 deficient bridges in need of replacement. The state utilizes standard bridge plans, which do not include complete plans for timber. However, temporary structures and timber plank on steel stringers are in the design manual. Average bridge costs for concrete structures are between $55 and $65 per square foot. Engineers favor reinforced concrete as a material choice.

In 1991, Virginia introduced its own timber bridge initiative through cooperation among the Virginia Transportation Research Council, Virginia Department of Transportation, University of Virginia, and Virginia Department of Forestry (Hilton, Sutherland, and Frame 1991). Through this program, one innovative timber bridge will be built in each of the nine highway districts. Evaluation of these structures will determine if further timber bridge work will progress.

Of the four states studied, Virginia engineers had the poorest perception of timber as a bridge material. The eastern side of the state has reportedly had decay problems with timber pilings after thirty years. Maintenance of timber decks on steel stringers was also considered a problem. Maintenance requirements and past performance of materials were the most important factors in the bridge decision in Virginia. Discussions with highway officials in the central and western parts of the state indicated they are receptive to attempts to utilize more timber and thought it may be a quick method for superstructure replacements. Some officials liked the idea of their own maintenance crews fabricating and installing timber decks. A lack of manufacturing facilities and initial cost were concerns at this time.

Twenty-eight treating plants and one glue-laminator are located in the state and could meet bridge needs. The state's 80 billion board feet of sawtimber is divided between one-quarter softwoods and three-quarters hardwoods. The oaks and yellow poplar are the predominant hardwood species, and Virginia and loblolly pine make up the majority of softwoods (USDA 1992). The state replaces an average of 125 bridges a year.

Other than the Timber Bridge Initiative and the Virginia Timber Bridge Initiative, there is little marketing activity. Marketing efforts need to get timber bridges in the design standards for the state. As in Mississippi, timber superstructure on concrete abutments appears to be the best alternative. Incentives include speed of installation, construction by state crews or local labor, cost competitiveness, and the current Virginia initiative.

Washington — Located in the heart of a large timber resource, one would expect this state to be receptive to timber bridges. Research identified 12 manufacturers or marketers of timber for bridge construction located in the Western United States. Over 12% of the nearly 7,000 bridges in Washington are classified as timber. Yet, only 3.4% of recent replacement bridges are timber. Perceptions of timber as a bridge material by highway officials were rated slightly above the national average at 3.91 on a scale from 1 to 7.

Each county in Washington has an engineer responsible for bridge replacement and maintenance. These engineers design, or hire outside consultants to design, their rural bridges. Highway appropriations are handled by the State local programs department, which is headed by a state DOT engineer. This group decides which bridges receive funding during any fiscal period, but has little influence over the design of the structure. State DOT engineers in the central office at Olympia review rural plans, but bridge standards are normally followed. The only standards for timber are in detour situations. The rural bridge decision is normally made by the county engineer in conjunction with a hired consultant. Washington has two distinct climates, which divide the state in half. West of the Cascade mountain range is quite humid, resulting in poor timber bridge performance. Decay is reportedly high and maintenance is often needed. The average reported lifespan is between 30 and 40 years. East of the mountains where it is quite arid, with low annual rainfall, timber is perceived relatively well. A lot of timber bridges were built in the late 30s and 40s during the WPA programs. Many of these in the eastern part of the state are just now being replaced. Prestressed concrete is the material of choice throughout the state. The availability and quality of concrete is a distinct competitive advantage for its use. The average cost of concrete bridges ranges between $60 and $70 per square foot.

Timber bridges are currently being built for aesthetic reasons. Only one of eight county engineers was receptive to timber bridges as regular alternatives for rural replacement. Concerns of depleting the old growth forest were quite common, and cost was another barrier to adoption in Washington. Only ten percent of the 170 billion board feet of sawtimber is in hardwoods, with red alder being the predominant species. Douglas fir and western hemlock make up over 70 percent of the softwood sawtimber (USDA 1992). Fifteen plants are available for wood treating within the state.

Marketing efforts need to be directed to state DOT engineers to establish standard plans for timber bridges. Maintenance and lifecycle cost were the most important factors in the bridge decision in Washington. These plans should stress timber superstructures on concrete abutments. Incentives in Washington include aesthetics, speed of installation, and long life east of the Cascade mountain range.

Wisconsin — Among those studied, this state has a unique system of highway maintenance with counties/towns responsible for all roads that fall within their jurisdiction including federal, state, county, and township. The counties work closely with the eight state DOT highway districts on bridge replacement. Each county is headed by a highway commissioner, who may or may not be an engineer, and is responsible for bridge replacement within the county. Most counties rely on private consultants to design their rural bridges. The state DOT has a maintenance/local programs engineer in each district who works with the county in bridge replacement.

Nearly 5,000 of the state's 13,000 bridges are classified as deficient. Wisconsin is one of only five states that has experienced an increase in timber bridges since 1986. This may be attributed to standard plans that include designs for timber and strong marketing efforts by two private timber bridge companies.

Nearly one-third of the state's 35 billion board feet of sawtimber is in softwoods (USDA 1988). Red pine, white pine, and jackpine represent the largest volume of softwoods, and aspen and the oaks make up the biggest volume of hardwoods.

Wisconsin was another state in which reinforced concrete was the material of choice among decision makers. Average reported costs for concrete bridges was between $45 and $55 per square foot. Decision makers in Wisconsin rated timber better than did decision makers in the other states studied. Decay was not a major concern, but maintenance and initial cost were barriers. Incentives included all-year construction, local labor, resistance to deicing chemicals, and aesthetics. Initial cost, maintenance requirements, and lifecycle cost were important decision-making factors for Wisconsin engineers. Marketing efforts by one bridge firm date back to 1955, and the state Association of Resource Conservation and Development has recently taken an active role in promoting timber bridges. A state study is currently underway in the state to determine county bridge needs and market potential. One glue-laminator active in the bridge program is located within the state, and fourteen treating plants can meet the requirements of treating wood for bridge manufacturers.

The county road commissioner is the initial contact for bridge replacement; however, the opinions of state DOT district and central engineers are heavily relied on. Private consultants are also strongly influenced by their customer, the state DOT.

Cost of timber is the primary barrier to DOT acceptance. Marketing efforts must address modern designs in the state standards, year-round construction, aesthetics, resistance to road salts, and use of semi-skilled labor.

Factors Important to the Adoption of Timber Bridges

The four states were compared to identify important factors which may influence the adoption of timber bridges. Of the factors measured, those classified under the headings of resources, familiarity, and conditions (Table 4) appear to be the most influential in the use of timber in rural bridges. The number of decision makers and the demand for bridges appear to have little impact on timber adoption.

Under these headings, the factors that appear to have the greatest impact on timber bridge adoption include:

- *a strong marketing effort*
- *standard bridge plans that include timber*
- *timber bridge familiarity by engineers and contractors*
- *severe climatic conditions that include the use of deicing chemicals and strong local rural road control*

The first three of these criteria are providing or supporting timber bridge information for highway officials. Deicing chemicals are one of the major factors for deterioration in concrete bridges (Dunker and Rabbat 1993). Local road control is important because these officials are closest to the rural bridge replacement decision. These factors are present in the state of Wisconsin, which has the highest perception of timber as a bridge material, and has seen an increase in timber bridge use since 1982.

Factors that appear to impede the adoption of timber bridges include:

- *strong state control*
- *high wood decay areas (humid climates)*
- *low cost of concrete bridges*
- *lack of standard plans that include timber*
- *lack of timber marketing efforts*

It appears that state engineers' design criteria for state highways influence their decision for rural roads. They are familiar with working with prestressed concrete on major highways, and consequently use it for local roads. High decay rates were reported in all regions except the Midwest, and for timber to be more widely accepted, this problem needs to be solved. In many areas, the cost of timber superstructures is exceeding the cost of complete concrete bridges. Until these costs are competitive, timber will continue to experience low adoption rates. A lack of standard timber plans and marketing efforts results in unfavorable usage of timber in these areas. Such factors are evident in Virginia and Mississippi, and these states represent regions that have the lowest perception of timber.

The amount/type of timber resource base, number of manufacturers, number of deficient bridges, and the number of timber bridges in the state appear to have little influence on the rate of adoption and perceptions of timber as a bridge material. There appears to be an inverse correlation between the number of timber bridges and the perceptions of timber. Mississippi has the largest number of timber bridges of states interviewed, and yet it has one of the lowest perceptions. This may be attributed to these bridges not being built to modern design or to any design standards.

Characteristics of Timber Bridge Adoption

Five characteristics of innovations that affect their adoption and rate of diffusion have been identified by Rogers and Shoemaker (1971) as:

- *relative advantage*
- *compatibility*
- *complexity*
- *trialability*
- *observability*

Recent timber bridge adoption may be characterized by these five characteristics as follows:

Relative advantage — Timber bridges have been promoted based on aesthetics, quick construction, resistence to road salts, and ease of construction. However, this study indicates that the decision maker may not perceive these as important advantages. Many of these bridge characteristics rated poorly or were not important in the bridge decision. Highway officials may not identify the relative advantage to using timber in bridges. This would support a niche strategy in which timber can be promoted in areas where these characteristics are important to the decision maker.

Compatibility — Less than one-half of the officials have been trained in timber design. All officials perceived timber to be more difficult to design than other bridge materials. This would indicate that timber is not compatible with the other bridge materials in the engineer's perception. Continued efforts are needed in the area of education that will assist the highway official in understanding timber bridge design. Efforts are needed to make modern timber bridges more compatible with current bridge structures.

Complexity — Although every effort has been made to assist the highway official in understanding new timber designs, officials may be unwilling to make the effort to learn these designs. Over seventy percent of respondents reported that their states had standard bridge plans. Yet, only thirty percent said these plans include timber. It is, therefore, more difficult and complex for the official to work with timber. Efforts are needed to have timber designs made standard for each state highway department. Continued efforts are needed to have AASHTO consider new timber bridge designs.

Trialability — The Timber Bridge Initiative has given every state the opportunity to try modern timber bridges. This study indicates that those individuals who have participated in the program or who have built a timber bridge in the past five years feel significantly better than those who have not tried timber bridges. This may indicate the trialability of timber for bridges has been successful. However, it is possible that those who have participated recently may have had better perceptions of timber to begin with, or the monetary incentives may influence their decision. Over time, the long-term performance of the modern timber bridge will play an important part in influencing the perceptions of highway officials about timber as a bridge material.

Observability — The opportunity presently exists for every state to observe the performance of modern timber bridges. Comparisons between modern timber bridges and non-timber bridges can now be made. Only with accurate information can highway officials make the best choices for rural bridge needs. The observability of timber bridges over a long period of time will play an important part in future perception and use of timber bridges.

Market Size

Much has been written about the potential market for timber in bridge construction. The estimates on the size of this market have ranged as high as 120 million board feet per year or 7,500 bridges (USDA 1991). Current average timber use for a bridge superstructure is estimated at 15,000 board feet (USDA, 1993). This research estimates a realistic size of the market from a customer point of view. During the mail survey, an open-ended question asked, "... where do highway officials feel is the best location for timber bridges?" Overwhelmingly, the response was low volume, low ADT (Average Daily Traffic), short span bridges in rural areas. While personal interviews were being conducted, officials were asked to define short span bridges and low volume roads. The mean responses were less than 46 feet in length and less than 350 vehicles per day.

In order to estimate the size of this market, data were requested from the Federal Highway Administration (FHWA 1993) concerning the bridges that fall within these parameters. The number of deficient bridges on United States' roads less than 46 feet in length with less than 350 vehicles per day (ADT) is 53,400 (Table 5). This represents a potential market of approximately 800 million board feet. However, only 5,700 bridges are replaced annually in the United States, and 6% of these are currently timber (FHWA 1992). This would equate to over 5 million board feet of timber currently used in bridge replacement. Yet, 14% of the bridges in the United States in this size category are timber. To maintain this level of timber bridges, approximately 12 million board feet of timber would be used annually.

The greatest potential for bridge replacement is in the Midwest and the South. These two regions account for nearly one-half of the deficient bridges less than 46 feet in length with less than 350 vehicles per day (ADT). These regions also account for one-half of the deficient bridges in length between 46' and 80' on roads with ADT below 350.

Although numerous estimates can be made on the amount of timber used in engineered timber bridges, these results indicate it is unlikely to exceed 10 to 15 million board feet annually. Until hardwood is cost competitive and design standards are fully implemented, the majority of bridges will continue to be southern pine or Douglas fir. This does not take into consideration bridges built by the USDA Forest Service on their roads or private developments. All of the four states studied have the resources to meet this demand.

MARKETING STRATEGIES

Marketing plays an important role in strategic planning by providing specific information about a products' market position and future opportunities which may exist. Companies can utilize this information to develop long-term plans for their growth into new areas. This study has provided needed information for the timber bridge industry and suggests the following strategies for continued expansion into the bridge market.

1. This study indicates that timber bridges will remain a specialty product which will have the most success in specific niche markets. Promoters of timber should develop a niche strategy in each specific geographical region they approach to meet the needs of the decision makers in that area. Such a niche strategy could be used where quick construction, beauty, or winter construction may be targeted. Other areas in which manufacturers can market include railroads, covered bridges, small landscape/foot bridges, and Forest Service bridges. Private developments or areas in which highway design loadings are not required may also provide opportunities.

2. Every effort needs to be directed at establishing timber standards that can be easily adapted to individual states. Providing bridge standards in computer aided design (CAD) form, will ease the adoption for engineers. Since much of the design is based on readily accessible standards, timber bridge promoters must make it easy for design engineers to choose timber.

3. Long-term performance of new timber designs must be monitored and reported in an educational format. Results should be transmitted through professional engineering literature or training seminars. Marketing practices must be directed at meeting the educational needs of the design engineer. Efforts need to be directed at state DOT engineers.

4. New designs need to stress superstructure replacement on concrete abutments or existing abutments for rehabilitation purposes. Promoters need to stress the new composites of wood and steel construction and divorce themselves of old timber bridge designs. Until wood preservatives can be developed that will guarantee 50-year lifespans, timber substructures will have slow adoption in humid or harsh environments.

5. Promoters of timber bridges need to utilize a variety of marketing practices including:

   a) the use of outside sales personnel to conduct missionary sales to highway officials
   b) engineering assistance to be able to provide answers to customers' (engineers') questions
   c) the development of educational and promotional literature for distribution

6. Prestressed concrete has been widely accepted because it is built under strict quality control standards, it is prefabricated, it is available in standard sizes for construction, and it is easily constructed with trained people. Modern prestressed timber bridges should be promoted in a similar fashion. All these factors can be applied to new timber designs. Manufacturing efforts should be directed at providing standard size members for bridges.

AREAS OF FUTURE RESEARCH

This study has revealed that numerous timber bridges are still being built with no design considerations. It is necessary to contrast the performance of timber bridges that have been built with specific design standards to other designed bridge materials. This study indicates that much of the perception of timber is based upon timber as a partial bridge material (decking) or as a stick-built project with no design. Engineering considerations must be taken into account when comparing the performance of all bridge materials. Long-term performance of designed timber bridges will need to be compared with performance of other bridge materials.

Another area that needs attention is the lifespan of treated timber in a bridge application. Properly treated timber is expected to last more than 50 years, yet in a dynamic loading situation (bridges), it is only lasting 30-40 years. What is occurring to shorten the lifespan of bridges made with treated timber? The problem may be attributed to construction practices, loosening of connectors, or extremely harsh environments. For timber bridges to be widely accepted, they will need to last in excess of 50 years with minimum maintenance.

This study concentrated on specific geographic areas and did not take into consideration the majority of states in the mid-section and southwestern United States. Results indicate that timber bridges may be most successful in arid or low decay areas. Information on perceptions of engineers and performance in these areas would greatly add to the understanding for timber bridge adoption.

This study applied only the top six factors to the decision model Analytic Hierarchy Process. Other bridge decision factors could be applied to broaden its scope. Factors such as aesthetics, ease of construction/repair, or resistance to deicing chemicals may prove to be marketing advantages of timber. If timber will not be the choice of an engineer with the most important bridge factors, it is possible that other factors may be better for the timber promoters to concentrate their efforts on.

LIMITATIONS TO STUDY

As with most investigations, not every aspect can be identified or anticipated. This study was developed to understand the factors that influence the design decision. The fact that many bridges are still being built with no design criteria affects these results. Many of these bridges are in the South, where there is the largest number of timber bridges and one of the poorest perceptions of timber as a bridge material. This indicates that perceptions may be based upon non-designed structures.

Another limitation is that only 28 states were included in the study. The results of the study indicate timber may perform better in arid or low decay regions. This work did not include the central or Southwestern United States. Perceptions and performance of timber may be higher in these areas, and factors that influence adoption could be different. The identification of these factors could assist in the adoption of timber bridges in other areas of the country.

This study focused on bridges built on rural roads maintained by the county or state. Timber is used on state and federal forest roads and occasionally in private developments. There may exist a small market for bridges less than 20' in length. The addition of this information would provide a more complete picture of the timber bridge potential in an area.

SUMMARY

This study has investigated several factors that will affect the future adoption of timber bridges in the United States. It applied the latest marketing techniques to bridge design decision makers in twenty-eight states. Direct comparisons were made of various bridge materials (prestressed concrete, steel, timber, and reinforced concrete) to identify timber's position in the bridge marketplace. Utilizing the Analytic Hierarchy Process led to the development of models that simulate how important factors influence the choice of a bridge material. The results of this examination indicate that timber is the poorest perceived bridge material, and in most cases, will be the last material chosen in the bridge decision. Finally, the first comprehensive examination of the timber bridge industry was undertaken to determine current marketing and management characteristics.

The realistic size of the market identified by design engineers would probably not exceed 700 bridges annually or 12 million board feet. This would represent nearly 12 percent of the bridges annually. The greatest potential is in the Midwest and South, where over 50% of short span bridges are located. The Southern or Eastern United States has the greatest potential for timber bridge manufacturing expansion, with a solid resource base, strong demand, and, currently, less competition. However, these regions had the lowest perception of timber, so strong marketing efforts would be needed for success.

In conclusion, this study indicates that timber bridges will remain a niche market until long-term performance improves and maintenance requirements decrease. Firms that utilize a niche strategy promoting timber's attributes based upon the area in which it is being marketed will be most successful. Competitive advantages of timber include ease and speed of construction, resistance to deicing chemicals, and ease of repair. Although local officials rate timber higher than other officials do, efforts must continue in establishing standard plans with state DOTs. Of the groups studied, state DOT personnel perceived timber to be the poorest performing material. This decision group is responsible for allocating Federal highway bridge funds.

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Table 1. Factors Affecting Timber Bridge Adoption

Conditions	1. Bridge ownership (State, county, etc.) 2. Bridge Costs 3. Maintenance policies, funding procedures 4. Legal and environmental conditions
Decision Makers	1. Perceptions of timber 2. Decision making structure 3. Choice of bridge material 4. Who makes the rural bridge material choice
Demand	1. Number of deficient bridges 2. Replacement strategies 3. Timber bridge market share
Familiarity	1. Number of demonstration bridges 2. Number of timber bridges in state 3. Current promotional activities 4. Previous experiences with timber bridges
Resources	1. Forest resource base 2. Manufacturing and treating facilities 3. Availability of bridge information and design 4. Engineering expertise (within government and private) 5. Climatic conditions

Table 2. Incentives for Timber Bridge Adoption as Reported by Decision Makers Across the United States

1. Timber bridges can be constructed very quickly, 2 to 3 weeks.
2. Timber bridges can be built all year in northern climates.
3. Timber bridges can be built with semi-skilled labor.
4. Timber bridges can quickly replace existing superstructure, while reducing dead load on bridge.
5. Timber bridges can be used where soil problems exist.
6. Timber bridges can be built easily by small contractors.
7. Timber bridges may allow shorter spans due to verticle abutments.
8. Timber bridges are easy to repair all times of the year.
9. Timher bridges are not affected by deicing chemicals.
10. Timber bridges have been used most for short spans (<40').
11. Timber bridges have aesthetic qualities that make them more "natural".
12. Timber bridges have lasted over 50 years when properly designed, treated, and constructed.

Table 3. Barriers to Timber Bridge Adoption as Reported by Decision makers Across the United States

1. Timber is perceived to have a shorter lifespan than other materials.
2. Timber is not as strong as other bridge materials.
3. Timber requires more maintenance than other bridge materials.
4. Timber is not a homogenous product and is difficult to test for compliance to standards.
5. Timber will wear out "physically" before other bridge materials.
6. Timber is more vulnerable to vandalism and fire damage.
7. There is a shortage of quality timber for bridge construction.
8. Timber is more difficult to inspect for internal decay.
9. Timber decay occurs often in pilings, abutments, and between deck and caps.
10. Timber does not perform well in humid or wet climates.
11. Deflection on timber decks causes wearing-surface problems.
12. There is no way to judge the long-term performance of modern bridges.
13. Timber bridges do not perform well on higher volume roads (>350 ADT).
14. Timber bridges do not perform well under high weight traffic-trucks.
15. Timber bridges have high initial cost.
16. Deep timber members can restrict hydraulic opening under bridge.
17. Environmental concerns about wood preservatives/timber supply.
18. Multiple piers with timber restrict waterways and collect debris.
19. There is a shortage of manufacturers to receive competitive bids.
20. Ice will damage abutments and piers during spring breakup.
21. TBI has led to high costs, complex designs, and unfamiliar species.
22. As number of concrete plants increase in state, timber is less competitive.
23. Prefabrication not always correct and causes problems at job site.
24. Delivery of material has not been very good with new designs.
25. There is a resistance of many DOTs to fund timber bridges.
25. Timber bridges may not fit structurally into all areas.

Table 4. Factors Affecting Timber Bridge Adoption in Four States

Bridge Factors	Mississippi	Virginia	Washington	Wisconsin
Conditions				
Rural bridge ownership	County	State DOT	County	County
Average total bridge cost of major bridge material	\$30-\$35/ sq.ft.	\$55-\$65/sq.ft.	\$60-\$70/ sq.ft.	\$45-\$55/ sq.ft.
Rural bridge maintenance responsibility	County	State DOT	County	State DOT
Does state have policies on treated wood?	No	Creosote not allowed	No	No
Number of certified prestressed concrete plants	2	6	4	5
Decision Makers				
Type of decision-maker in state	County/ State DOT	State DOT/ Consultant	County/ Consultant State DOT	State DOT County/ Consultant
Overall perceptional rating of timber as bridge material	3.37	3.31	3.91	4.30
Engineers' overall choice of bridge material (AHP)	Prestressed Concrete	Reinforced Concrete	Prestressed Concrete	Reinforced Concrete
Bad experiences with timber as bridge material	Decay/ Short life	Decay/ Maintenance	Short life	Heavy loads/ Design
Engineers' expected life of timber in bridges	25-30 years	30-40 years	30-40 years	40-50 years
Demand				
Number of deficient bridges	8000	4000	1800	5000
Average number of bridges/year	225	120	55	215
Number of timber bridges built from 1985-1992	258	2	13	68
Timber bridges as a percentage of all bridges built since 1985	17%	0.2%	3.4%	4.8%

Table 4. (cont'd) Factors Affecting Timber Bridge Adoption in Four States

Bridge Factors	Mississippi	Virginia	Washington	Wisconsin
Familiarity				
Timber Bridge Initiative projects from 1989-1993	8	3	6	4
Total timber bridges in state as of 1992	4026	67	876	536
Timber bridges as a percentage of all bridges	20%	0.5%	12.7%	4.1%
Is there an active marketing effort by timber bridge promoters?	No	None till TBI	Little	Active since 1955
Are contractors familiar with timber bridges?	Yes	Moderately	Yes	Yes
Are design engineers familiar with timber bridges?	No	Moderately	Yes	Yes
Resources				
Timber resource	Southern Pine/ Southern Hardwoods	Appalachian Hardwoods/ Southern pine	Douglas Fir/ Hemlock/ Red Alder	Northern Hardwoods/ Red Pine
Does state have standard timber bridge plans?	No	Planks on Steel	Detours only	Yes
Climatic conditions	Hot/Humid/ Coastal	Moderate/ Coastal	Coastal/ Arid	Moderate/ bad winters
Number of "timber bridge" plants in state	0	0	0	1
Number of wood treating plants and (Glu-lam plants)	10 (0)	28 (1)	15 (1)	14 (1)

Table 5. Estimation of Timber Bridge Market Size based on Federal Highway Administration Inventory (FHWA 1993)

State/ Region	Total Bridges in Region	Average Bridge Replacement per year	Bridges <350 ADT 20'-45' (deficient)	Bridges <350 ADT 46'-80' (deficient)	Bridges 350-1000 ADT 20'-45' (deficient)	Bridges 350-1000 ADT 46'-80' (deficient)	Potential Timber Market (deficient)
Mississippi	16,609	225	3416 (2041)	3162 (1621)	684 (137)	535 (178)	7797 (3977)
South	140,128	1415	26,504 (12,439)	13,567 (6603)	7139 (1244)	3788 (1021)	50,998 (21,307)
Virginia	12,652	120	2786 (855)	695 (287)	941 (257)	242 (74)	4664 (1473)
Mid-atlantic	67,063	650	15,186 (5267)	5638 (2306)	5511 (1840)	2259 (847)	28,594 (10,260)
Washington	6674	55	1079 (201)	593 (109)	320 (52)	186 (31)	2178 (393)
Northwest	46,189	355	6164 (1454)	3339 (884)	2027 (383)	1339 (265)	12,869 (2986)
Wisconsin	12,963	215	3815 (1310)	1348 (346)	864 (232)	375 (100)	6402 (1988)
Midwest	131,573	1560	37,340 (12,860)	17,319 (5109)	7291 (1872)	3434 (761)	65,384 (20,602)
Northeast	50,358	360	8063 (4230)	3400 (1887)	3620 (1578)	1712 (838)	13,735 (8533)
States not in study	141,454	1350	43,215 (17,150)	16,149 (7152)	9261 (1615)	3173 (894)	71,798 (26,811)
Totals:	576,765	5690	136,472 (53,400)	59,412 (23,941)	34,849 (8532)	15,704 (4626)	246,438 (90,499)

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